



### Repairing Chipped Silicide Coatings on Refractory Metal Substrates

Two methods have been demonstrated to be feasible.

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The space shuttle orbiter's reaction control system (RCS) is a series of small thrusters that use hypergolic fuels to orient the orbiter in space. The RCS thrusters are constructed from a special niobium-based alloy — the C-103. This alloy retains excellent mechanical properties from cryogenic temperature all the way up to 2,500 °F (1,370 °C). Despite its excellent, high-temperature properties, C-103 is susceptible to rapid oxidation at elevated temperatures. Were the naked C-103 alloy exposed to the operational thruster environment, it would rapidly oxidize, at least losing all of its structural integrity, or, at worst, rapidly “burning.” Either failure would be catastrophic. To prevent this rapid oxidation during thruster firing, the RCS thrusters are coated with a silicide-based protective coating — the R512a. Over time, this protective coating becomes weathered and begins to develop chips. Launch Commit Criteria limit the diameter and depth of an acceptable pit; otherwise, the thruster must be removed from the orbiter — a very costly, time-consuming procedure. The authors have developed two methods to repair damaged R512a coatings on C-103.

For the first repair technique, metal foundries, semiconductor manufacturers, and many other industries have developed and routinely use coatings that can easily be painted on metal to protect it from corrosion, including oxidation, to temperatures in excess of 2,500 °F (1,370 °C). These coatings are typically a well-chosen oxide in a special organic binder that adheres to metallic surfaces. The organic binder is se-

lected, so that upon exposure to elevated temperature, the ceramic is held in proximity to the substrate and forms somewhat of a chemical bond to the surface. If the binder is freed from the surface, the ceramic deposit remains and maintains an effective oxygen barrier. Commercially available, off-the-shelf ceramic paints may be used to repair chipped R512a and protect the underlying C-103 from subsequent oxidation. The authors have identified several candidates that aid in the protection of C-103. This first repair technique is considered somewhat temporary. The ideal use for the ceramic paints would be to repair an RCS nozzle when a chip is discovered, say, at the launch pad. It would serve as a protective coating for at least one mission, prevent the rollback of the shuttle, and postpone the replacement of the nozzle until a more opportune time in the ground-processing flow.

The second repair technique is based on using the native coating material of the RCS nozzles. In this case, the chipped area is ground out and a “green” R512a coating is applied to the repair area. After the green coating has dried, it must be heated at extreme elevated temperatures while in vacuum or inert atmosphere to initiate the solid-state reaction between the R512a and the C-103. In the early 80's, a repair process was developed using a variant of the native coating and a focused quartz lamp to heat the local area. Due to the bulky size of the lamp and focusing assembly, only the areas along the outer periphery of the nozzles could be repaired. The authors have devel-

oped a technique using a fiber-coupled, high-powered laser as heat source to successfully fuse the green R512a to C-103. The resulting repaired areas on test coupons are chemically and structurally equivalent to the native coated areas. Since the fiber-coupled laser assembly is quite small and easy to handle, all areas of the nozzle are accessible for repair, including the throat area. Since this repair technique results in a protective barrier that is equivalent to the original coating, it is considered to be a permanent repair. Thermal modeling and calculations have shown that during the fusing process, all other areas of the nozzle remain within specifications, so that the processes are viable *in situ* on actual thrusters, although not while they are installed on the orbiter.

The two techniques are complementary in the sense that the ceramic paints are easily applied and do not require excessive temperatures. While not as desirable as the permanent repair, they could be applied for moderate protection until the permanent laser-repair technique is available to the repair area. Both repair techniques were originally intended for RCS nozzles, but the process could easily be applied to other geometries of R512a/C-103. Additionally, the two repair techniques may be adapted to other high-temperature coating/substrate systems.

*This work was done by Robert Youngquist of Kennedy Space Center and Christopher D. Immer and Francisco Lorenzo-Luaces of ASRC Aerospace. Further information is contained in a TSP (see page 1). KSC-12690/29*

### Simplified Fabrication of Helical Copper Antennas

From concept to working prototype takes just a few hours.

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A simplified technique has been devised for fabricating helical antennas for use in experiments on radio-frequency generation and acceleration of plasmas.

These antennas are typically made of copper (for electrical conductivity) and must have a specific helical shape and precise diameter.

Such an antenna could be made by bending a single long piece of copper tubing or bending smaller pieces of copper tubing, then welding the pieces to-

gether. It could also be made by machining from a single large piece of copper. It is extremely difficult to bend copper tubing into a helix with a precise pitch and diameter. It is also difficult to create the helical shape from multiple pieces of tubing; moreover, welding separate pieces distorts the shape. Machining a hollow cylindrical helix from a block or cylinder of copper entails the use of a complex, expensive, three-dimensional-milling machine in a process that entails long setup and machining times.

In the present simplified technique, one begins by creating a two-dimensional paper template of a desired helical antenna shape. The template is pasted on the outer surface of a copper pipe that has the desired inner and outer diame-

ters. Holes are drilled at the locations where corners are required to exist in the final helical antenna. Manually, using a hacksaw, diagonal cuts are made in the outer cylindrical surface of the pipe, following the lines on the template. Usually, after hacksawing, only a little filing is needed to smooth the edges of the resulting antenna. If the antenna must be water-cooled, then copper tubing can be brazed onto the outer surface of the antenna. This tubing is not required to follow the precisely defined shape of the antenna.

This fabrication technique would not be suitable for mass production, but it is ideal for a laboratory environment. The advantages of the this technique are the following:

- Precise antennas can be made from inexpensive, stock-size copper pipes.
- No welding of separate pieces is needed, and so there is no welding-induced distortion of antenna shapes.
- Prototype antennas can be fabricated fairly rapidly, without the need for complex three-dimensional-milling machines or computer-aided drafting tools.
- Notwithstanding the reliance on handwork, the total fabrication time (as little as a few hours) is competitive with, and probably less than, that of any automated process that could be used for this purpose.

*This work was done by Andrew Petro of Johnson Space Center. Further information is contained in a TSP (see page 1).  
MSC-24076*